

An Examination of the Leading Indicators of Phase E Cost and Staffing Growth and Methods for Their Use

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Introduction

Problem Statement

In the creation of project cost estimates for interplanetary, robotic missions, primary focus is generally given to the crafting of cost estimates for the development of a flight system: Phases B, C, and D. Many times, efforts expended to develop cost estimates for operations (Phase E) are less rigorous than that devoted to estimates for Phases B through D. The Project may be challenged to develop a solid estimate of operations cost in the early stages of mission development, e.g., Mission Concept Review (MCR), Preliminary Design Review (PDR), as the details of the flight system and payload capabilities and mission plans may yet to be sufficiently understood.

Many times, the methods of engineering build-up (“grass roots”) or taking a percentage of flight system development cost are used to estimate operations cost. Phase E can include cost and schedule risks that are not anticipated at the time of the major milestone reviews prior to launch. If not incorporated into the engineering build-up cost method for Phase E, this may translate into an estimation of the complexity of operations and overall cost estimates that do not cover the full scope of operations and the associated technical risks. As a result, many projects have found themselves with thin reserves during cruise and on-orbit operations, and exceed their operations budget, inclusive of the reserve.

Introduction

Objectives

- Some recent studies have determined the major drivers of cost and staffing growth in Phase E of robotic, space science missions. As part of a 2012 study, Aerospace identified leading indicators of Phase E cost and staffing growth.¹
 - *Both qualitative and quantitative approaches were used to identify these indicators.*
 - *Leading indicators may be present as early as PDR or CDR.*
- The objectives of this paper are
 - *Review these leading indicators and discuss specific methods and practices for their use*
 - *Consider the various ways different stakeholders may leverage these indicators*
 - *Present a number of objectives that, if met, could lead to improved operations planning and cost estimation. Discuss steps to meet these objectives*
- This paper prompts discussion on specific actions to reduce excursions from Phase E cost estimates and staffing plans.

Background

Findings from Studies of Cost and Staffing Growth

- In comparison to studies of cost growth in development of flight systems, a relatively small number of studies have focused on operations cost and staffing growth.
- Some recent studies do speak to contributing factors to cost growth, in general, and specifically regarding operations.
 - National Research Council (NRC) study, “Controlling Cost Growth of NASA Earth and Space Science Missions” ²

In general, the earlier the initial estimate, the more the cost will grow

... competitive pressures encourage (overly) optimistic assessments of the cost and schedule impacts of addressing uncertainties and overcoming potential problems. As a result, initial cost estimates generally are quite optimistic, underestimating final costs by a sizable amount, and that optimism sometimes persists well into the development process.

Background

Findings from Studies of Cost and Staffing Growth

- NASA Marshall Space Flight Center study, “Life Cycle Cost Growth Study for the Discovery and New Frontiers Program Office”

Inadequate planning for operations (phase E) resulted in significant [Life Cycle Cost] impacts.³

The majority of underlying causes [of cost growth] are embedded in the project approach during the [concept study and preliminary design] phases, but the actual cost or schedule impacts typically are not experienced until late in the development or operations phases.⁴

Insufficient resources and effort are assigned to defining an operations concept and estimating costs during the proposal and phase B activities.⁵

Underestimating operations costs results from

- *Underestimating the complexity of mission operations,*
- *Inadequate planning for sustaining engineering, and/or*
- *Ignoring special requirements for long duration missions, e.g., knowledge retention, software and hardware refresh, technology evolution, institutional staffing considerations.⁶*

Inadequate planning for the development of operational tools often results in software development being delayed in Phase E, pushing development costs into the operations phase.⁷

Background

Findings from Studies of Cost and Staffing Growth

- The Aerospace Corporation study, “Understanding Cost Growth During Operations of Planetary Missions: An Explanation of Changes” identified drivers of cost growth.⁸
 - *Launch slips due to changes in manifest and slow funding from agency*
 - *Increased mission operations and science support due to lengthening of Phase E*
 - *Project Management, Mission Assurance and System Engineering (PM/MA/SE) costs generally underestimated during pre-launch milestone reviews and post-launch*
 - *Underestimated complexity of mission planning and navigation issues*
 - *Need for more detailed and advance planning for encounters*
 - *Resolution of spacecraft anomalies and resultant flight software patches, and resolution of other flight system technical issues*
 - *No estimates or significant underestimates for flight system and payload/instrument support*
 - *Increases in contractor costs*

Methods to Effect Change

Leading Indicators of Cost Growth



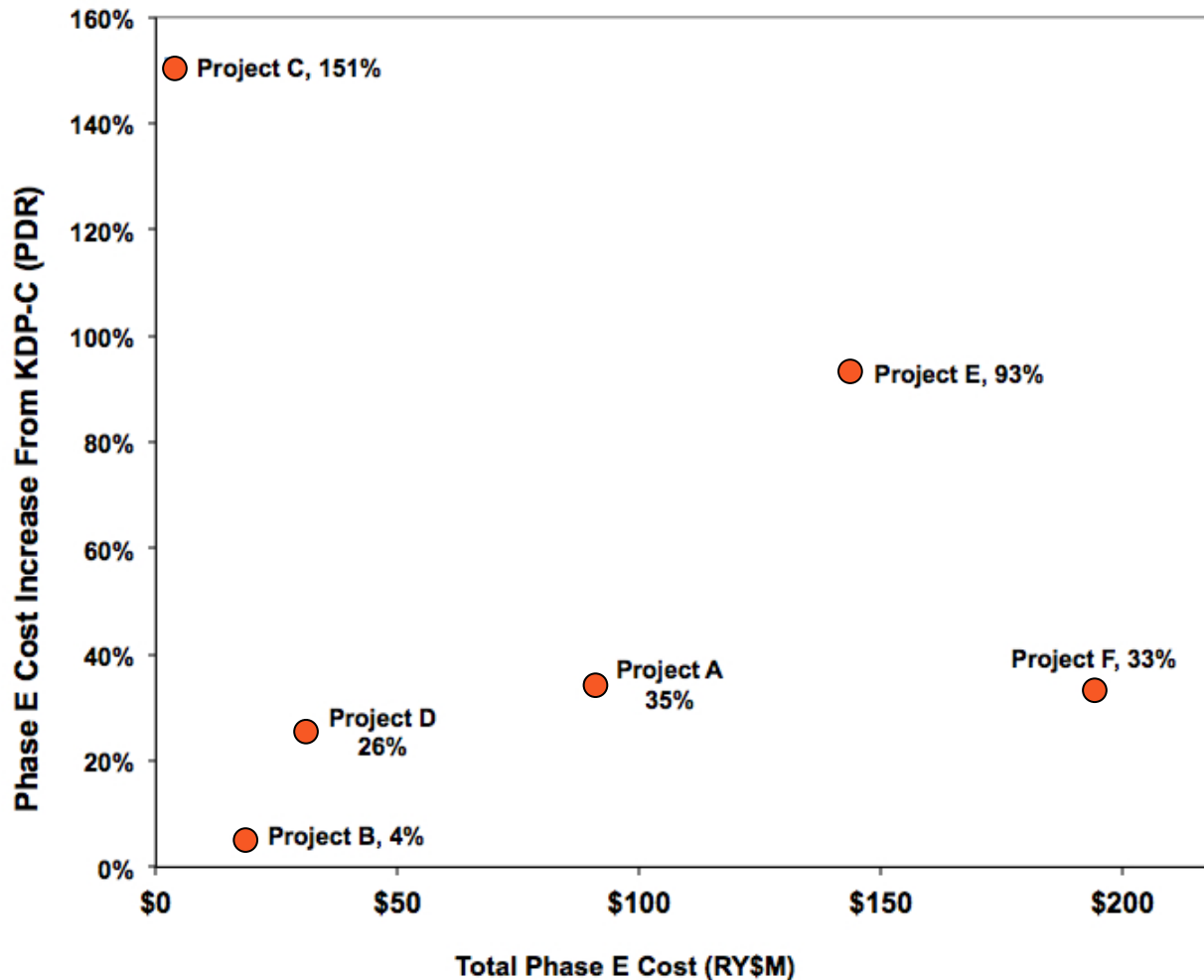
Leading Indicators of Cost Growth

Phase E Explanation of Changes Study, 2011 - 2012

- The Aerospace Corporation completed the Phase E Explanation of Changes study with the following objectives.
 - *Determine areas of growth across set of six interplanetary missions studied*
 - *Understand the primary reasons for cost and staffing growth in Phase E, also referred to the “Explanation of Changes” (EoC)*
 - *Uncover leading indicators of Phase E cost growth and identify objective and quantifiable leading indicators that may suggest growth as early as PDR or CDR*
 - *Provide observations and recommendations*
- The six missions varied in total mission cost, total Phase E cost, and primary mission periods. The missions were selected based on accessibility to data and to project personnel. Some mission characteristics are given below.
 - *Primary missions ranged from just under 1 year to 12 years in length (extended missions data were not included in the study)*
 - *Total Phase E costs ranged from \$3.6M to just over \$190M*
 - Three missions, <\$50M; primary missions between 6 months and 1 year
 - Three missions, >\$90M; primary missions between 8 and 12 years

Leading Indicators of Cost Growth

Phase E Cost Growth



For the six projects examined as part of the Phase E Explanation of Changes study (Projects A through F), the chart displays the percent cost increase from the Phase E cost estimates at or near PDR.

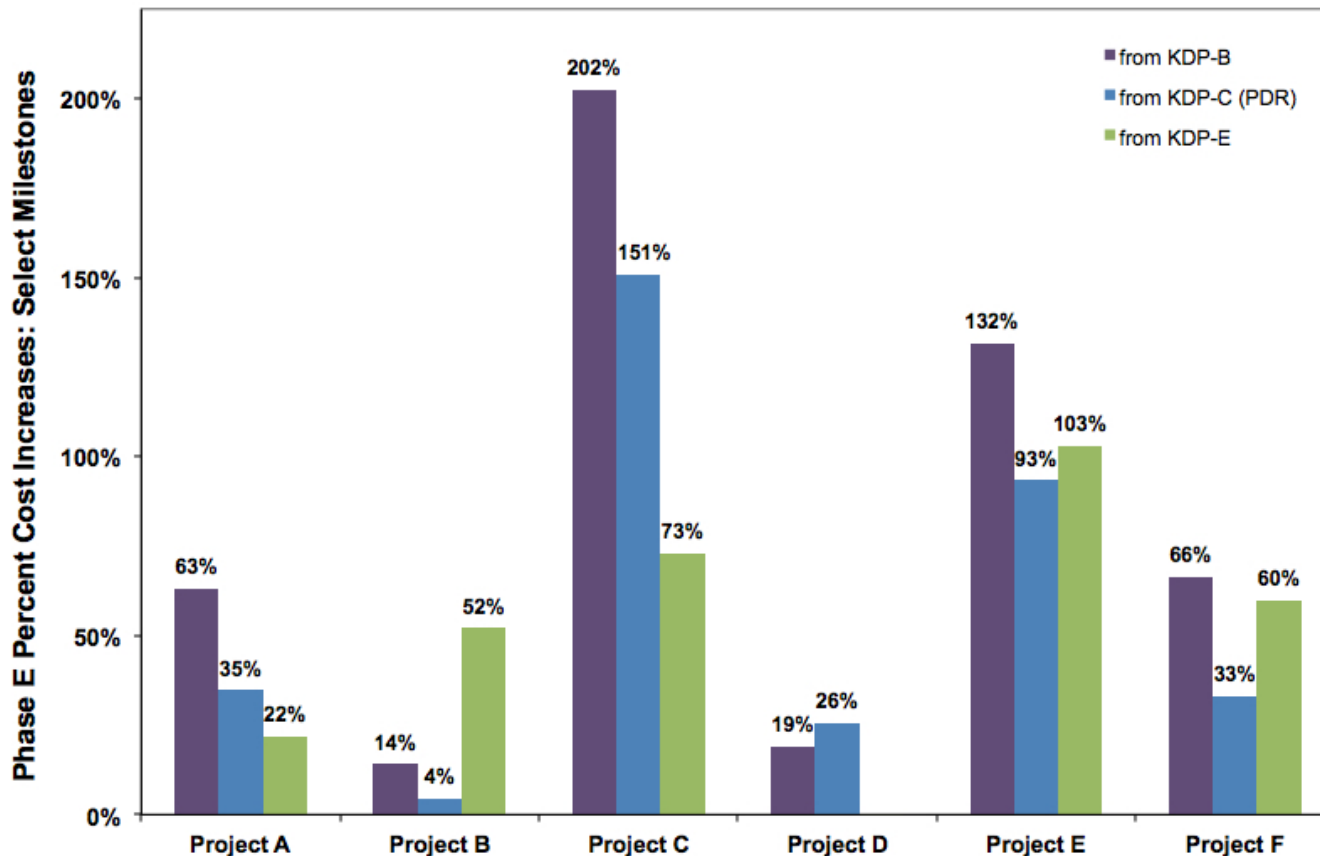
Projects B through D have relatively smaller total Phase E costs than others in the mission set.

The primary mission periods for Projects B through D were much shorter relative to the other missions.

Figure A: Plot of Phase E Cost Growth for Six NASA Missions versus Total Phase E Cost (Data as of June 2011)

Leading Indicators of Cost Growth

Phase E Cost Growth from KDP-B, KDP-C, and KDP-E



As shown on this chart, in most cases, the percent growth in Phase E cost estimates is less when measured from PDR than if measured from KDP-B, i.e., cost estimates generally improve given more mature operations concept, mission and flight system designs.

Figure B: Plot of Phase E Cost Growth for Six NASA Missions from Different Life-Cycle Gates: KDP-B, KDP-C, KDP-E
(Data as of June 2011)

Leading Indicators of Cost Growth

Approach

As part of the study, we used both a quantitative and qualitative approach to identifying objective metrics that may suggest Phase E cost growth.

- *Qualitative Approach*
 - *Reviewed reasons for Phase E cost growth between KDP-B and KDP-C and the most recent year of actuals or estimates at completion (EAC)*
 - *Examined the series of questions and answers with various project managers from site visits as well as the review packages if provided*
- *Quantitative Approach*
 - *Reviewed cost and FTE data between KDP-B and KDP-C across WBS Level II*
 - *Examined FTE cost profiles over Phase E*

Leading Indicators of Cost Growth

Analysis and Findings

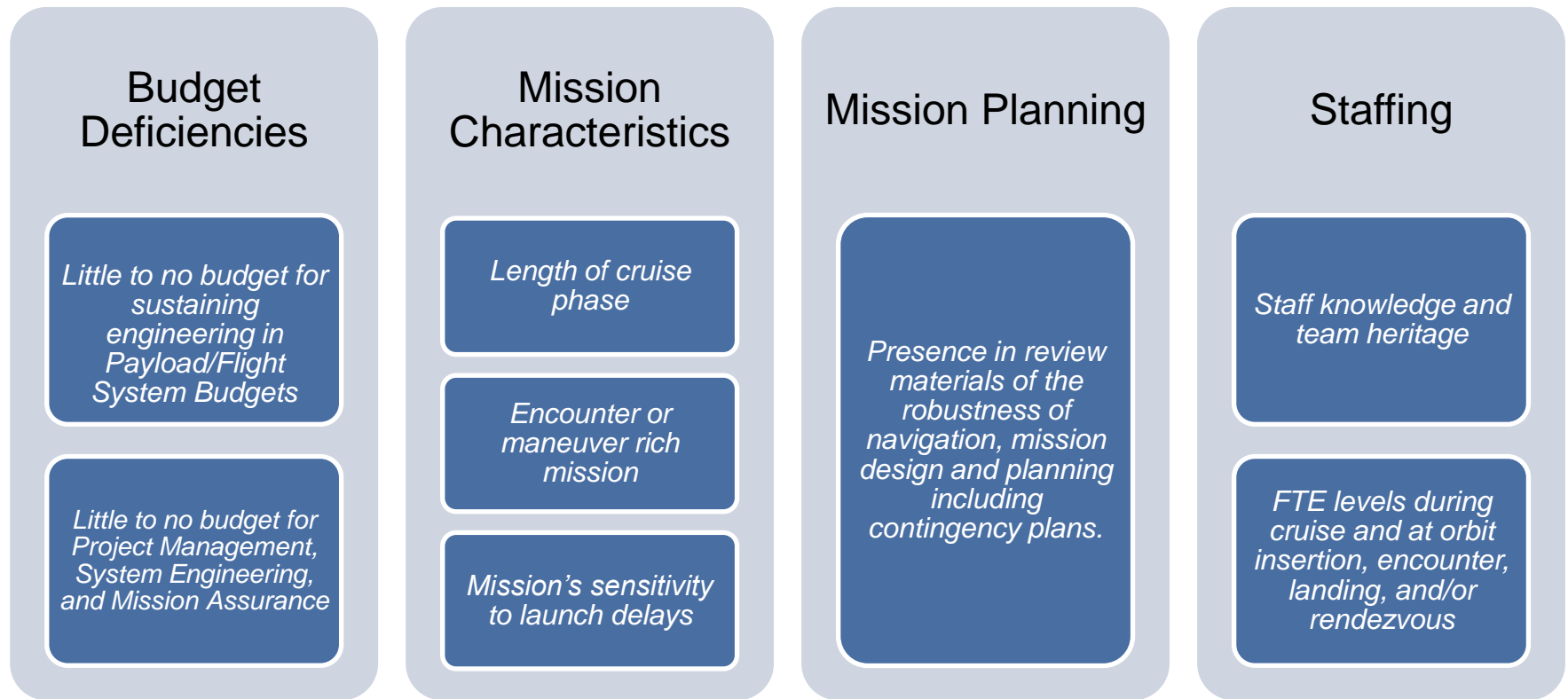


Figure C: Set of leading indicators of possible Phase E cost growth as early as PDR and CDR

Leading Indicators of Cost Growth

Analysis and Findings – Payload and Flight System Budgets

Budget Deficiencies

Little to no budget for sustaining engineering in Payload/Flight System Budgets

For three of six missions studies, there were no explicit allocations for sustaining engineering in Phase E for payload and flight systems.

- Examples of Reasons for Budget Growth
 - *Additional resources needed to resolve on-orbit anomalies*
 - *Flight software engineers needed to develop and upload software; for this study, this is allocated to the Flight System WBS element*
- About the Payload and Flight System Cost and FTE Increases
 - *Sustaining engineering allocation for Project F at CSR and PDR was 0% and then grew to 29% of Phase E EAC in FY12 or \$46M*
 - *Sustaining engineering allocation for Project E at CSR and PDR was 0% and grew to 13% of Phase E EAC in FY12 or \$18M*
 - *Average percentage of sustaining engineering of Phase E EAC for examined missions was 23%, ranging from 0% to a high of 65%*

Leading Indicators of Cost Growth

Analysis and Findings – PM/SE/MA Budgets

Budget Deficiencies

*Little to no budget
for Project
Management,
System
Engineering, and
Mission Assurance*

All six missions studied in the Explanation of Change study encountered marked increases in PM/SE/MA for various reasons.

- Examples of Reasons for Growth in PM/SE/MA Budgets
 - *Additional planning to address complexity of operations during encounters*
 - *Addition of MA management and need for adequate configuration management*
 - *Resolution of navigation issues*
 - *Resolution of on-orbit anomalies*
- About the PM/SE/MA Cost and FTE Increases
 - *FTEs for Project A grew from 4 at CSR to 31 in FY11 (675% increase)*
 - *Phase E cost for Project E increased by 100% between KDP-B and FY12; \$9M to \$18M*
 - *Average percentage of PM/SE/MA of Phase E Estimate at Completion (EAC) for examined missions was 15%, ranging from a low of 6% to a high of 26%*

Leading Indicators of Cost Growth

Analysis and Findings – Length of Cruise Phase

Mission Characteristics

Length of cruise phase

Assumptions regarding spacecraft autonomy and lowered operations cost that may be acceptable for missions with short to medium cruise phases may not be applicable for missions with multiple year, extended cruise phases. Also, with extended cruise comes added risk of on-orbit anomalies and the need for sustaining engineering.

- Examples of Reasons for Growth Based on Length of Cruise Phase
 - *On Project F at CSR, the project had taken an aggressive stance in presenting an operations plan with a very small team and the relatively autonomy of the spacecraft during cruise. On-orbit anomalies and an initial underestimate of mission planning complexity led to a marked increase in FTE and thus cost.*

Leading Indicators of Cost Growth

Analysis and Findings – Encounter or Maneuver Rich Mission

Mission Characteristics

*Encounter or
maneuver rich
mission*

A mission with a numerous set of trajectory maneuvers to accomplish various encounters, flybys, and orbit insertion can carry more risk than those with relatively few. The number of encounters generally drive the number of rehearsals required by the mission planning team. Initial mission design efforts may be underestimated and on-orbit anomalies can also add to cost risk. This issue was present in two-thirds of missions examined.

- Examples
 - *For Project E at CSR and PDR, the project carried no budget for science planning during Phase E. Due to a launch slip, substantial mission design and science planning were required.*
 - *On Project B, a very significant effort was put on mission design for the encounter.*
 - *On Project F, encounter planning and additional risk reduction activities related to navigation and contingency planning contributed to cost growth.*

Leading Indicators of Cost Growth

Analysis and Findings – Mission Sensitivity to Launch Delays

Mission Characteristics

Mission's sensitivity to launch delays

Although generally not known until late in Phase D, launch delays can seriously impact Phase E cost. Whether or not a mission's trajectory design is substantially sensitive to launch delays is something that is known a priori. Mission designs should have known contingency plans and the cost impacts should be explored.

- Examples
 - *For Project E, a launch delay of 5-months required a replan of the mission design and extended cruise period. ~15% growth in the period of Phase E. Cost growth between the estimates at PDR and post-launch was about \$37.4M.*
 - *For Project F, the launch delay resulted in an additional two years of operations. Between CSR and the first year of Phase E, this represented a \$60M and 200 FTE increase in EAC.*

Leading Indicators of Cost Growth

Analysis and Findings – Absence of Thorough Discussion of Navigation Planning

Mission Planning

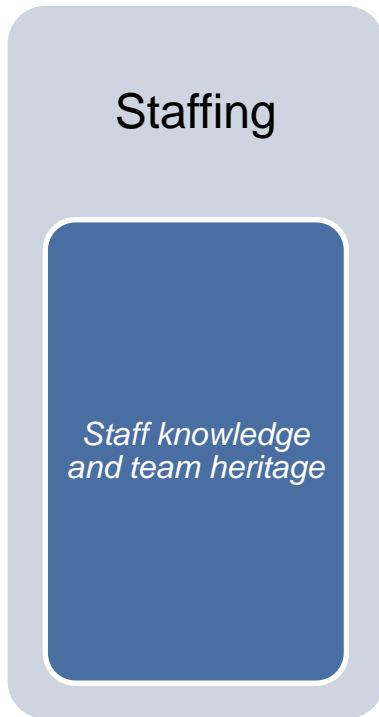
Absence in review materials of the robustness of navigation, mission design and planning including contingency plans.

This indicator is similar to that of the encounter or maneuver rich missions. A thorough discussion of navigation planning should be held as part of a pre-launch review.

- Examples
 - *Project A underwent a significant replan to address inadequate planning for target encounter.*
 - *On Project B, a very significant effort was put on mission design for the encounter. An working group was stood up to address this urgent need.*
 - *On Project F, encounter planning and additional risk reduction activities related to navigation and contingency planning contributed to cost growth*

Leading Indicators of Cost Growth

Analysis and Findings – Staff Knowledge and Team Heritage



The average years of experience of Phase E management as well as the supporting team's experience base on operations tasks is a “soft” yet significant leading indicator.

- Examples of Reasons for Growth Based on Team Heritage
 - *On Project B, project personnel interviewed revealed concerns around team experience and resident knowledge*
 - A major contractor/partner in Phase E support was new to deep space missions. This contributed significantly to risk and the overall cost of the contract.
 - The Phase D development of mission design and planning was one of the most significant issues for the project. A working group was stood up to address this, and significant resources went into the development of encounter planning for the success of the mission.
 - Phase D development delayed the launch
 - Added Phase E staff to handle mission complexity

Leading Indicators of Cost Growth

Analysis and Findings – FTE Levels During Various Phases of Flight

Staffing

*FTE Levels during
cruise and at orbit
insertion,
encounter, landing,
and/or rendezvous*

The examination of profiles in FTE by fiscal year for the missions with multiple years in Phase E can help inform an evaluation of future missions. The Aerospace cost model leverages this method.

- Observations of FTE Profiles
 - *For missions in this study with multiple years of Primary Mission, the range of FTE values at cruise was (27,42) with an average of 32 FTE. For all missions in this study at or over one-year of operations, the range of FTE values at encounter, orbit insertion or landing was (55,75) with an average of 64 FTE.*
 - *Note that these ranges are from a small data set and would be enhanced by the inclusion of additional missions and their related FTE data.*

Leading Indicators of Cost Growth

Some Specific Recommendations

Based on study findings, specific guidance and recommendations were crafted for use by stakeholders who generate and/or review cost estimates.

- **Budgets for PM/SE/MA and Payload/Flight Systems**
 - *Look for PM/SE/MA Phase E budgets that are 10 – 20 % of total operations budget*
 - *Similarly, Payload and Flight System budgets that are roughly 20 – 25% of total*
 - *Determine rationale for excursions outside these ranges*
- **Encounter or Maneuver Rich Missions**
 - *Detail in the discussion of staffing and resource allocation to navigation and mission planning at various periods of flight*
 - *Consider what types of peer reviews might be needed for mission design/planning*
- **Staff Knowledge and Team Heritage**
 - *Inclusion of team heritage and years of experience as part of review packages in areas of Mission Operations and Ground Data Systems. Look for some discussion of the seniority of team members in the various roles required for operations.*
- **Sensitivity to Launch Delays**
 - *At CDR and ORR, some detailed discussion of contingency planning based on launch delays with consideration of cost impacts for contingencies*

Leading Indicators of Cost Growth

Some Specific Recommendations continued

- **Robustness of Navigation, Mission Design, Planning and Contingency Plans**
 - *At CDR and ORR, adequate detail and robustness in the discussion of navigation planning. Consider what types of peer reviews might be needed for this planning.*
- **Length of Cruise Phase**
 - *At CDR and ORR, ensure that the operations plan contains adequate contingency planning and associated cost margin to handle some frequency of on-orbit anomalies that might degrade a spacecraft's autonomy.*
- **Regarding FTE Levels**
 - *CDR review packages to include FTE profiles for Phase E broken out by a standard WBS to level 2*
 - *For cruise phase, staffing levels within the range of 25 to 50 FTE.*
 - *For encounter, orbit insertion, landing or rendezvous, staffing levels during these periods between 50 and 80 FTE.*
 - *Determine rationale for excursions outside this range*

Methods to Effect Change

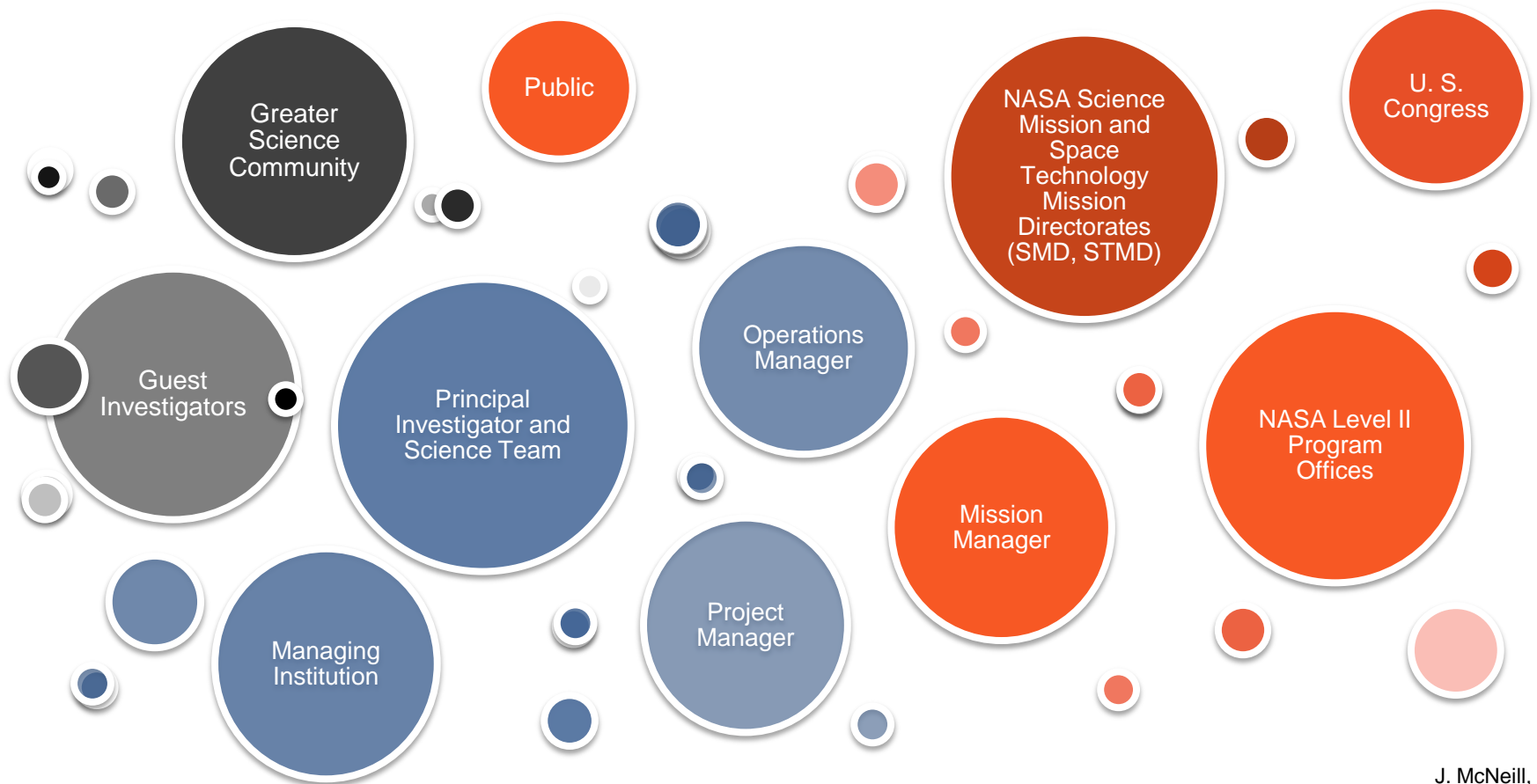
Stakeholders, Processes and Practices



Stakeholders

Definition

At a high-level, it is helpful consider the stakeholders (active and passive) as a way to appropriately frame a discussion about successful missions and the processes and practices to mitigate Phase E cost and staffing excursions.



Processes and Practices

Thoughts on Improving Operations Planning and Cost Estimation

The following objectives could contribute to improved operations planning and cost estimation. The steps towards each range from the specific to the broad and overarching.

Objective A: Increase level of detail and robustness of Phase E cost and staffing estimates

- *In advance of the PDR and subsequent reviews for operations, review teams should independently vet the Phase E cost and staffing estimates, operations concept, and Phase E reserve plan for consistency and appropriate detail.⁹*
- *Given the mission plan, Phase E duration, and target, consider how the operations plans, specifically staffing estimates and related costs, by WBS functional area, compares with other missions.*
- *For the review of the cost estimate, consider the specific recommendations based on the Leading Indicators of Cost Growth, noted earlier in this presentation. Look for appropriate discussion of contingency plans in the operations concept and, if contingencies need to be exercised, the expected impacts on Phase E staffing and cost.¹⁰*
- *When available, use relatively recent historical data from the managing institution to inform the assessment.*

Stakeholders*: Project and Operations Managers; NASA Level II Program Office

* For each objective, the possible primary and active stakeholders are given.

Processes and Practices

Thoughts on Improving Operations Planning and Cost Estimation

Objective B: Enhance the focus on operations planning to aid cost estimation

- *Consider decoupling the milestone reviews of operations-related materials from the milestone reviews of the flight system, e.g., Mission Operations Center (MOC) development, Phase E cost estimates.*
- *Envision what this might look like, i.e., separate reviews at appropriate points in the Project Life Cycle. Include an appropriate level of review after the PDR and prior to the Operational Readiness Review (ORR) to ensure the maturity of MOC development and the robustness of the Phase E cost estimates*

Stakeholders: *Managing Institutions; NASA SMD, STMD, Level II Program Office, Office of Evaluation*

Processes and Practices

Thoughts on Improving Operations Planning and Cost Estimation

Objective C: Ensure the quality of Phase E historical cost and staffing data in the NASA archive. Incentivize use of Phase E historical data at the managing institutions.

- *Ensure the timely, systematic, and accurate capture of detailed Phase E staffing and cost historical data and its incorporation into the NASA archive, e.g., Cost Analysis Documentation Requirement (CADRe), One NASA Cost Engineering (ONCE). This could require improvements in the means of transmitting information from the Project and Program Offices to the NASA repositories, i.e., ways other than transcribing values from project materials in flat-file format.¹¹*
- *Survey a representative set of institutions with a history of space systems operations and document best practices in the way they collect, archive, and communicate data and information on past missions' Phase E costs and related lessons learned.*
- *Disseminate and discuss the results of this survey within the stakeholder community and provide incentives for the implementation of the practices with the most promise. Consider the incorporation of these practices in the appropriate NASA guidance materials and handbooks.*

Stakeholders: *Managing Institutions, Project and Operations Managers, NASA SMD, STMD, Office of Evaluation*

Processes and Practices

Thoughts on Improving Operations Planning and Cost Estimation

Objective D: Broaden general knowledge of the operations risks, cost threats, and drivers of operations cost growth

- *Conduct additional research in this area and broaden the set of missions studied. To date, a relatively small number of missions have been included in the studies with the objective of understanding the reasons and explanations of Phase E cost growth. In contrast, a recent study focusing on the quantitative analysis of Phase E cost growth included 20 missions.¹²*
- *Share findings and recommendations on this subject with stakeholders for the purpose of education and promoting action. Submit this information for review and incorporation into the appropriate NASA guidance materials and handbooks.*

Stakeholders: *Managing Institutions, Project and Operations Managers; NASA SMD, STMD, Level II Program Offices, Office of Evaluation*

Processes and Practices

Thoughts on Improving Operations Planning and Cost Estimation

Objective E: Review and discuss other acquisition models for space systems operations

- *Review the acquisition model(s) used in other government agencies for developing and sustaining space system operations. For example, flight systems developed for Earth orbit by some non-NASA agencies may be acquired separately from the systems to operate them.*
- *Some questions to consider*
 - In what ways could such a model be tailored to work for space science missions, and how would this be managed?
 - What are the circumstances that would best suited to this?
 - How tightly coupled is mission operations execution to flight system development?
 - What are the pitfalls and the advantages of changing the approach to acquiring operations capabilities for missions?
- *Invite primary stakeholders to discuss the findings and consider what future paths could be taken to leverage them.*

Stakeholders: NASA SMD, STMD, Office of Evaluation

Conclusion



Conclusion

- A number of studies document Phase E cost and staffing growth. A few studies examine the reasons or explanations for such growth.
- The Aerospace Phase E Explanation of Changes study identifies a set of leading indicators of Phase E cost and staffing growth and provides specific recommendations and guidance on how to employ these indicators. These leading indicators may be present as early as PDR. Review teams, cost estimators, and other stakeholders may leverage this information for their benefit. Additional research in this area should be completed.
- After reviewing various studies and existing NASA guidance materials, specific objectives to improve operations planning and cost estimation have been identified.
 - *Increase the level of detail and robustness of cost and staffing estimates for operations*
 - *Enhance the focus on operations planning to aid cost estimation*
 - *Improve and ensure the quality of Phase E historical data in institutional archives*
 - *Broaden knowledge of the operations risks, cost threats, and drivers of operations cost growth*
 - *Review and discuss other acquisition models for space systems operations*
- The steps towards each of the objectives range from specific to broad and overarching. This paper is meant to initiate conversation on material changes in processes and practices involving the stakeholders.

Conclusion

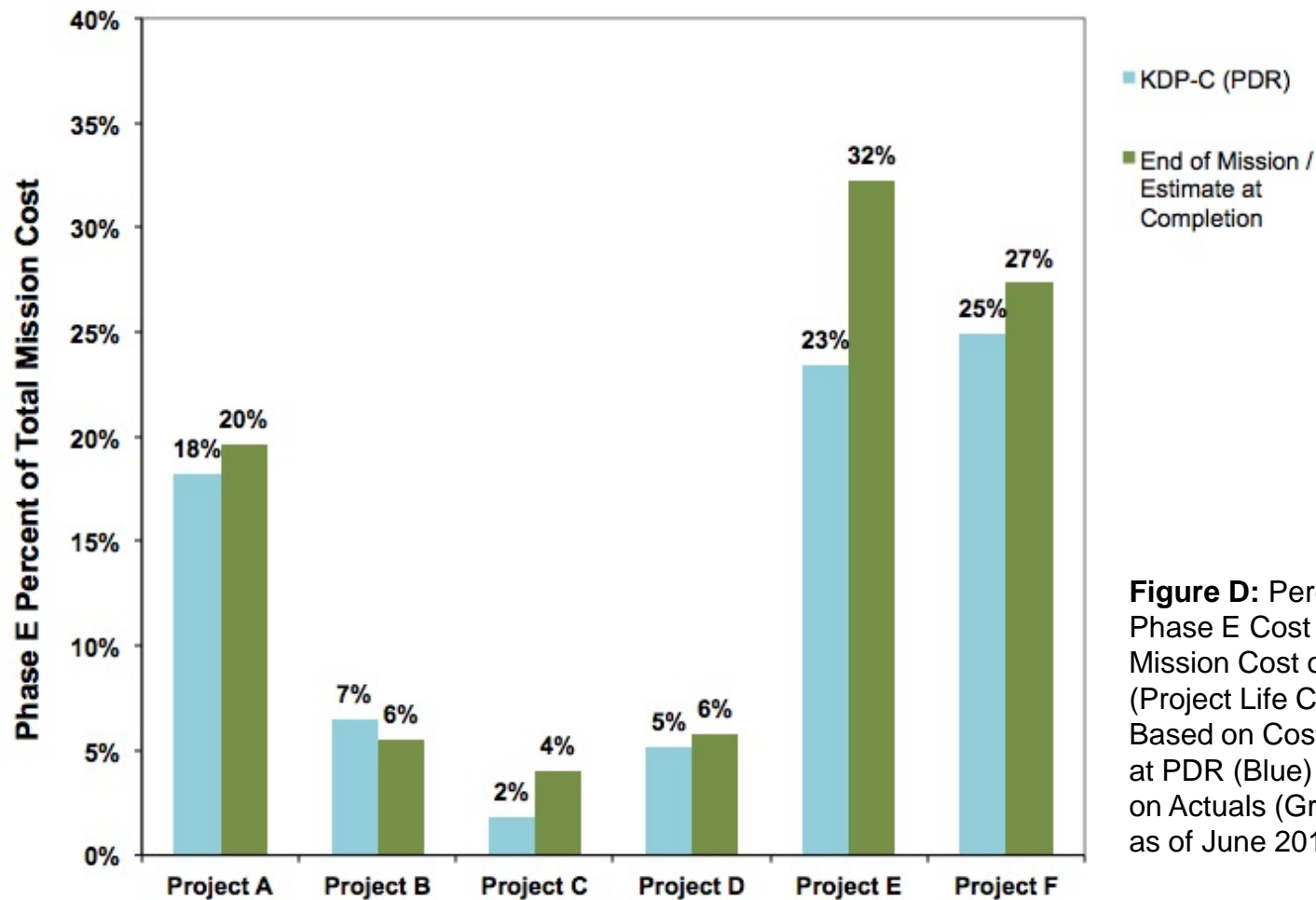


Figure D: Percentage of Phase E Cost of Total Mission Cost or EAC (Project Life Cycle Cost) Based on Cost Estimates at PDR (Blue) and Based on Actuals (Green); data as of June 2011

For some missions, operations cost constitute about a third of EAC, underscoring the need to codify processes and best practices for Phase E cost estimation and review.

Thank you.

NOTE: All trademarks, trade names, and service marks are the property of their respective owners.

End Notes

- 1) J. F. McNeill, Jr., E. L. Chapman, M. E. Sklar, 2013. Understanding Cost Growth During Operations of Planetary Missions: An Explanation of Changes. IEEE Paper #2115, IEEE Aerospace Conference, Big Sky, Montana. March.
- 2) National Research Council. 2010. Controlling Cost Growth of NASA Earth and Space Science Missions. The National Academies Press, Washington, D.C. 2, 5
- 3) B. Barley, P. Gilbert, M. Newhouse, 2010. Life Cycle Cost Growth Study for the Discovery and New Frontiers Program Office. NASA Marshall Space Flight Center.
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- 4) Barley et al, 4
- 5) Barley et al, 15
- 6) Barley et al, 14
- 7) Barley et al, 15
- 8) McNeill et al, 5 – 7
- 9) Barley et al, 6
- 10) McNeill et al, 10
- 11) NASA Office of Evaluation. 2008. 2008 NASA Cost Estimating Handbook. <http://www.ceh.nasa.gov>, page 1-56
- 12) B. Bitten et al. 2012. Phase E Cost Analysis for NASA Science Missions. AIAA Space 2012 Conference, Pasadena, California. September.

Supplemental Slides

Excerpts from paper by McNeill et al, “Understanding Cost Growth During Operations of Planetary Missions: An Explanation of Changes”

Explanation of Changes

Reasons for Growth and Major Themes

- External to NASA and Project
 - *Launch slips due to changes in manifest and slow funding from agency*
 - *Extended length of Phase E for two missions; subsequent cost and FTE increases*
- Internal – PM/MA/SE
 - *Generally underestimated during pre-launch milestones and early in Phase E*
 - *Underestimated complexity of mission planning and navigation issues*
 - *Resolution of spacecraft anomalies and other technical issues*
- Internal – Science
 - *Launch slips that extended Phase E length and led to increased science support*
 - *Higher than expected complexity of mission planning impacted science team and science planners*

Explanation of Changes

Reasons for Growth and Major Themes

- Internal – MOS/GDS
 - *Mission complexity issues contributed to MOS staffing increases*
 - *Detailed advanced planning for encounters*
 - *Unanticipated additional staffing to handle in-flight anomalies*
 - *Change in mission (co-manifest) and its impact*
 - *Increases in contractor costs*
- Internal – Flight Systems/Payload
 - *Three of the four missions either had no estimates or significant underestimates for support in this area at early milestones and early in Phase E*
 - *Resolution of spacecraft anomalies and resultant flight software patches*
 - *Unanticipated spacecraft or instrument issues*
- Internal – Other
 - *Underestimates of Education and Public Outreach (EPO)*

Explanation of Changes

Findings and Recommendations

- 1) Ensure that estimates for a full complement of engineering support (general systems engineering, sustaining support for flight systems and payload/instruments) are included in project budgets and staffing at all major milestone reviews.

This support is critical to resolve in-flight anomalies and to develop appropriate contingency plans. The managing NASA Centers or institutions and the Principal Investigators should consider reviewing their own historical data to understand appropriate levels of engineering sustainment during Phase E as part of their proposal development and during the development phases of the mission.

- 2) Factor the cost of flight software builds and uploads into Phase E budgets

On-orbit anomalies may result in unexpected revisions and uploads of flight software or modifications to ground software.

- 3) Ensure that project management and missions assurance estimates are reviewed during early milestone reviews.

During our site visit interviews, some Project Managers commented on the higher than expected effort in program management during operations. If PM/SE/MA budgets are funded at levels significantly less than 10 to 20 percent of the total Phase E budget, then the project should examine this and discuss the rationale for the lower level.

Explanation of Changes

Findings and Recommendations

- 4) Do not underestimate the potential complexity in mission design and planning. Numerous missions recorded the miscalculation of complexity.

The uniqueness of the various missions' objectives can make this difficult to address.

- 5) A shortening of Phase E period does not always translate to lower total Phase E cost.
- 6) Carefully and formally consider the impact of launch slips or the impact of additional (new) mission requirements after CDR on operations period, cost, and staffing levels.
- 7) Contractor and team heritage is important when looking at cost and schedule risks. Contractors or teams that have not previously been involved in deep space missions will have a learning curve, and in the end, this may impact the project's overall effectiveness and productivity.
- 8) The set of leading indicators of cost growth cited in Figure G may be useful to reviews of projects at major milestones.

These should be useful in uncovering potential cost and schedule threats. To further improve the review processes and enhance focus on Phase E issues, a checklist can be constructed from these and used during reviews.

- 9) Contingency planning should be a component of the overall plan for Phase E. Thus, a formal discussion of contingencies should be incorporated in major milestone reviews of the operations plan.

A number of "what if" scenarios should be discussed and presented as part of operations planning. This planning may capture various paths that were not considered in the initial basis of estimate for the creation of the Phase E cost estimate.